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6. AUTHOR(S)

Stavros A. Zenios

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Decision Sciences Dept
The Wharton School
Univ of Pennsylvania
Philadelphia, PA 19104

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13. ABSTRACT *(Maximum 200 words)*

A massively parallel algorithm for nonlinear multicommodity flow problems has been designed and tested. A new promising algorithm for quadratic stochastic programs with network structures has also been developed.

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FINAL REPORT
PARALLEL and VECTOR COMPUTING for NONLINEAR NETWORK OPTIMIZATION

AFOSR Grant 89-0145. Joint with NSF CCR-8811135.

PI: Stavros A. Zenios
Decision Sciences Department
The Wharton School
University of Pennsylvania
Philadelphia, PA 19104.

1 Major Accomplishments

We have made significant progress on the design and implementation of parallel algorithms for large scale problems with network structures. Our research emphasizes both paradigms of parallel computing: (1) Coarse-grain decompositions on small scale parallel architectures (e.g., CRAY Y-MP), and (2) Fine-grain decompositions on massively parallel architectures(e.g., Connection Machine CM-2). Two achievements stand out from our progress todate:

1.1 Solving Multicommodity Network Problems

We have designed a massively parallel algorithm for nonlinear multicommodity network flow problems, Zenios [21]. The algorithm has been implemented on a Connection Machine CM-2 with upto 64K processing elements. The implementation for dense transportation problems runs at 3 GFLOPS. A sparse implementation – for arbitrary network topologies – runs at approximately 400 MFLOPS. We have experimented with quadratic programs with 10^7 columns and 10^5 rows. Solution times range from a few minutes to 1 hour. A study comparing our methods with existing technology – including interior point algorithms – is under way. At this point we feel that no other method can solve quadratic programs of this size.

We have also designed a decomposition method for linear/nonlinear multicommodity flow problems, Zenios, Pinar and Dembo [22]. Our approach here is based on a smoothed linear/quadratic penalty (LQP) method combined with a simplicial decomposition. The specific algorithmic choices we have made appear very successful in solving the large Patient Distribution System(PDS) problems generated by the Air Force. (A comparative table is attached). The algorithm is also well-suited for vector computing and coarse grain parallelism, as reported in Pinar and Zenios [1990].

1.2 Solving Stochastic Network Problems

Dealing with uncertainty using optimisation is a problem that dates back to the early days of linear programming. Unfortunately, stochastic programming models can grow in size very rapidly. We have designed an algorithm for quadratic stochastic programs with network structures. The algorithm induces a fine-grain decomposition of the problem. It has been implemented on the Connection Machine CM-2 and used to solve some financial modeling problems. This work is at a very early stage but results are very encouraging.

2 The Impact on Applications

1. We have solved the patient distribution system (PDS) models successfully. We appear to have the most efficient method among those reported in the literature.

2. Professor Rick Rosenthal from the Naval Postgraduate School has contacted us with a problem for scheduling marines for training programs. It appears that a model formulation fits into a network framework and can be solved by our algorithms. Discussions on this problem are under way.

3. A problem from Navy personnel scheduling was brought to us by Dr. J. Krass –San Diego Laboratory. Current models have been proven unsolvable by existing network algorithms and the problem is currently being solved using heuristics. We are currently working with Dr. Krass to generate the problem data in the format required by our solvers.

3 Industry Participation

Some of our research on financial modeling applications using supercomputers has attracted interest from both the finance industry and computer industry. Digital Equipment Corporation made an equipment award of $1.7M to establish the HERMES Laboratory for Financial Modeling and Simulation. Union Bank of Switzerland is sponsoring a project in the Laboratory on parallel computing models for mortgage–backed financing. Fujitsu Research (Japan) has expressed interest in sponsoring another project.

4 Graduate Student Supervision

Five graduate students, one MBA student and a full time research associate are involved with different aspects of this research. Mr. M. Pinar defended successfully his Dissertation proposal on "Coarse–Grain Decomposition of Network Structured Problems". Mr. S. Nielsen will be defending his dissertation proposal on "Massively Parallel Algorithms for Network Structured Problems". Mr. E. Chajakis completed a Master's thesis on "Synchronous and Asynchronous Parallel Implementations of Relaxation Methods for Network Problems" and he is now developing a PhD dissertation topic. All students have co–authored at least one paper that has been accepted for publication. The remaining graduate students are at earlier stages. The research associate and the MBA student are involved with the activities of the HERMES Laboratory.

5 Publications

The working papers and publications that acknowledge the AFOSR support are given in this section.

1. S.A. Zenios and M.S. Shtilman, "Constructing Optimal Samples from a Binomial Lattice", Decision Sciences Department, Report 90–04–05, University of Pennsylvania, Philadelphia, 1990.(submitted)

2. S.A. Zenios and J.D. Hutchinson, "Financial Simulations on a Massively Parallel Connection Machine", Decision Sciences Department,

Report 90-04-01, University of Pennsylvania, Philadelphia, 1990, (Revisions required by the Intnl. Journal of Supercomputing Applications).

3. S.A. Zenios and S.S. Nielsen, "Massively Parallel Algorithms for Singly Constrained Nonlinear Programs", Decision Sciences Department, Report 90-03-01, University of Pennsylvania, Philadelphia, 1990. (submitted)

4. S.A. Zenios and Y. Censor, "The Proximal Minimization Algorithm with D-Functions" , Decision Sciences Department, Report 89-12-17, University of Pennsylvania, Philadelphia, 1989. (submitted)

5. S.A. Zenios, "Parallel Monte-Carlo Simulation of Mortgage Backed Securities" *Financial Optimization*, Cambridge University Press, (to appear).

6. S.A. Zenios, S.S. Nielsen and M.C. Pinar, "On the Use of Advanced Architecture Computers via High-Level Modeling Languages", *Impact of Recent Computer Advances on Operations Research*, Publications in Operations Research Series, Vol.9:507-518, Elsevier Science Publishing Company, New York, N.Y., 1989.

7. C. Phillips and S.A. Zenios, "Experiences with Large Scale Network Optimization on the Connection Machine", *Impact of Recent Computer Advances on Operations Research*, Publications in Operations Research Series, Vol.9:169-180 Elsevier Science Publishing Company, New York, N.Y., 1989.

8. S.A. Zenios and Y. Censor, "Vector and Parallel Computing with Block-Iterative Medical Image Reconstruction Algorithms", Medical Image Processing Group, Report 88-09-10, Hospital of the University of Pennsylvania, 1988. (submitted)

9. S.A. Zenios, "A Note on the Solution of Very Large Matrix Balancing Problems", *Proceedings of 1989 Advanced Computing for Social Sciences Conference*, Williamsburg, VA.

10. S.A. Zenios and S-L. Iu, "Vector and Parallel Computing for Matrix Balancing", *Annals of Operations Research*, 22:161-180, 1990.

11. S.A. Zenios, "Matrix Balancing on a Massively Parallel Connection Machine", *ORSA Journal on Computing*, 2(2):112–125, Spring 1990.

12. H. Dahl, A. Meeraus and S.A. Zenios, "Some Financial Optimization Models I. Risk Management", Decision Sciences Department, Report 89–12–01, The Wharton School, University of Pennsylvania, Philadelphia, 1989. (submitted)

13. H. Dahl, A. Meeraus and S.A. Zenios, "Some Financial Optimization Models II. Financial Engineering", Decision Sciences Department, Report 89–12–02, The Wharton School, University of Pennsylvania, Philadelphia, 1989. (submitted)

14. E.D. Chajakis and S.A. Zenios, "Synchronous and Asynchronous Implementations of Relaxation Algorithms for Nonlinear Network Optimization", *Parallel Computing* (to appear).

15. S.A. Zenios, R. Qi and E.D. Chajakis, "A Comparative Study of Parallel Dual Coordinate Ascent Implementations for Nonlinear Network Optimization", *Large Scale Numerical Optimization*, T. Coleman and Y. Li (eds.), SIAM, pp. 238–255, Philadelphia, 1991.

16. S.S. Nielsen and S.A. Zenios, "Mixed-Integer Nonlinear Programming on Generalized Networks", Decision Sciences Department, Report 89–09–12, The Wharton School, University of Pennsylvania, Philadelphia, 1989. (submitted)

17. S.N. Nielsen and S.A. Zenios, " A Massively Parallel Algorithm for Nonlinear Stochastic Network Programs", Department of Decision Sciences Report 90–09–08, The Wharton School, University of Pennsylvania, Philadelphia, 1990.

18. G.T. Herman, D. Odhner, K.D. Tonnies and S.A. Zenios, " A Parallelized Algorithm for Image Reconstruction from Noisy Projections", *Large Scale Numerical Optimization*, T. Coleman and Y. Li (eds)), SIAM, pp. 3–21, Philadelphia, 1991.

19. Y. Censor and S.A. Zenios, "Interval Constrained Matrix Balancing", *Linear Algebra and Its Applications*, 1991, (in print).

20. S.A. Zenios and Y. Censor, "Massively Parallel Row-Action Algorithms for Some Nonlinear Transportation Problems", Decision Sciences Department, Report 89-09-10, The Wharton School, University of Pennsylvania, Philadelphia, 1989. (submitted)

21. S.A. Zenios and M.C. Pinar, "Parallel Block-Partitioning of Truncated Newton for Nonlinear Network Optimization", Decision Sciences Department, Report 89-09-08, The Wharton School, University of Pennsylvania, Philadelphia, 1989. (submitted)

22. S.A. Zenios, "On the Fine-Grain Decomposition of Nonlinear Multicommodity Transportation Problems", Decision Sciences Department, Report 90-09-07, The Wharton School, University of Pennsylvania, Philadelphia, 1990.

23. S.A. Zenios, M.C. Pinar and R.S. Dembo, "Linear-Quadratic Penalty Functions for the Solution of Multicommodity Network Flow Problems", Report 90-12-05, Decision Sciences Department, The Wharton School, University of Pennsylvania, Philadelphia, 1990.

24. M.C. Pinar and S.A. Zenios, "Parallel Decomposition of Multicommodity Flows using Smooth Penalty Functions", Report 90-12-06, Decision Sciences Department, University of Pennsylvania, Philadelphia, 1990.